Appendix P – Sediment Resuspension/Aquatic Plant Growth

Modeling the Effects of Fetch Reduction on the Potential for Persistence of Sago Pondweed in Marsh Lake, Minnesota River System

2 April, 2010

William F. James
ERDC Eau Galle Aquatic Ecology Laboratory
W. 500 Eau Galle Dam Road
Spring Valley, Wisconsin 54767

Objectives:

The objectives of this research were to explore the potential for improving underwater light climate in shallow Marsh Lake (Minnesota) to promote growth and reproduction of Sago Pondweed for waterfowl habitat. An empirical sediment resuspension model was used to evaluate the effects of island establishment on reduction in fetch and wind-generated sediment resuspension, and improvement in light attenuation. A submersed macrophyte growth model (SAGO) was used to evaluate the potential for growth and persistence of Sago Pondweed under current and future conditions.

Methods:

The critical bottom shear stress (τ_c) of sediments in Marsh Lake was determined experimentally using a particle entrainment simulator (PES) designed exactly as described by Tsai & Lick (1986). The PES consisted of a vertically-oscillating, perforated acrylic grid that was driven by a computer-controlled motor. The grid was positioned so that the bottom of its oscillation cycle occurred exactly 5.08 cm (2 inches) above the interface of an intact sediment core. A cam on the motor shaft allowed the grid to oscillate up and down for a distance of 2.54 cm (1 inch).

Intact sediment cores, 10 cm in depth, were collected using a 15 by 15 cm box corer (Wildco Wildlife Supply Company, Saginaw, Michigan) for determination of τ_c. The sediment contained in the box corer was transferred to a 13 cm (5 inch) diameter by 20 cm acrylic cylinder by carefully slipping the cylinder over the sediment enclosed by the box core sleeve and sliding a thin plexiglass disk underneath the cylinder to contain the sediment. The sediment cores were stored in cushioned coolers filled with water and transported to the laboratory via vehicle with water overlying the sediment to minimize changes in physical characteristics (moisture content and density) that would have occurred due to desiccation. In the laboratory, the overlying water was removed and 1.36

L (to a height of 5 inches) of local tap water was then carefully siphoned onto the sediment surface of the sediment core system.

To determine τ_c, the motor of the PES was programmed to oscillate above the sediment interface in a stepwise manner from 0 to 800 revolutions per minute (RPM) at 100 RPM increments every 10-min intervals. At 8 min into each RPM cycle, a 50 mL sample was collected 2.54 cm below the water surface using a peristaltic pump. Water removed as a result of sampling was simultaneously replaced with filtered lake water using a peristaltic pump. Samples were analyzed for TSS and turbidity. Values were corrected for dilution effects by replacement water. RPM was converted to τ using the calibration curve developed by Tsai & Lick (1986; Fig. 5, page 317) for levels ranging between 430 and 750 RPM. I used linear interpolation to estimate τ for levels that occurred below 450 RPM and above 750 RPM. Thus, τ ranged from 0 to nearly 6 dynes cm^{-2}. The τ_c was estimated as the inflection point where TSS and turbidity increased in the water column above background conditions. Sediment collected at historical station 1 (James and Barko 1994) was used to determine τ_c. Sediment resuspension was predicted to occur at this station when calculated bottom τ exceeded τ_c.

The theoretical bottom τ was calculated as:

$$\tau = H\left[\frac{\rho\left(\upsilon(2\pi / T)^3\right)^{0.5}}{2\sinh(2kh)}\right]$$

where τ is the calculated bottom shear stress, H is the wave height (cm), ρ is the density of water (1 g cm^{-3}), T is the wave period (s), v is the kinematic viscosity, k is the wave number (2π/L where L = wave length, cm), and h is the water depth (cm). Since H, T, and L are related to effective fetch (CERC 1977), shear stress will change (i.e., decline) as a function of decreasing fetch due to island placement.

The concentration of TSS (C_{TSS}; mg L^{-1}) in the water column at station 1 was predicted using the equation (Bengtsson & Hellström, 1992; Hamilton & Mitchell, 1996; Bailey & Hamilton, 1997):

$$C_{TSS} = C_e + C_{background} + (C_i - C_e - C_{background}) \bullet \exp\left(\frac{-\omega_s}{h} t\right)$$

where C_e is the TSS equilibrium concentration when sediment resuspension balances sediment deposition, $C_{background}$ is the TSS concentration under quiescent periods, C_i is the initial TSS concentration, ω_s is the depth-averaged settling velocity (cm s^{-1}), h is the depth of the water column (cm), and t is the time step (seconds). The ω_s of particles was determined via particle size analysis (Plumb 1981). C_e was estimated from the following equation:

$$C_e = 0$$

when $\tau_c < \tau$

$$C_e = A\left(\frac{\tau - \tau_c}{\tau_{ref}}\right)^n$$

when $\tau_c > \tau$

where τ_{ref} is 1 dyne cm^{-2} (i.e., to make τ dimensionless; Luettich et al., 1990; Hamilton and Bailey 1996); and A and n are constants determined via regression analysis of resuspended TSS concentration versus excess τ. The resuspension model was calibrated against TSS information collected at station 1 in 1992 (James and Barko 1994). A summary of values used as model parameters for determination of TSS are shown in Table 1.

The model POTAM (Best and Boyd 2003a and b) was used to simulate Sago Pondweed growth and tuber production at station 1 under 1992 conditions with and without fetch reduction due to island establishment. Inputs to the model included a daily light attenuation coefficient (k_d), water depth, and water temperature. k_d was estimated from simulated TSS using the regression relationship $k_d = 0.097 \cdot TSS + 0.942$ developed for Peoria Lake, Illinois (James et al. 2004). The model was initialized using model defaults developed for northern temperate regions of the United States. The initial tuber dry mass was 0.155 g DW tuber^{-1}, the dormant tuber number density was 240 tubers m^{-2}, and the tuber number per plant was set at 8. The model was run for a 5 year period using estimated daily k_d for 1992 as input for each year. The tuber dry mass produced at the end of the growing season was used as input for the next year and so on.

Summary of Results:

Variations in turbidity versus shear stress for an intact sediment core subjected to the particle entrainment simulator are shown in Figure 1. Turbidity was low and relatively constant below 2 dynes cm^{-2}. Above a critical shear stress of 2.3 dynes cm^{-2}, turbidity increased substantially. During 1992, high TSS concentrations in the water column coincided with peaks in wind speed in May, mid-June, and September through November (Figure 2). There was generally good agreement between simulated and observed TSS. The model overpredicted TSS in May; however, observed values represented an average of a daily sample that was composited at 8-hour intervals whereas simulated results represented instantaneous values.

Variations in mean daily TSS and daily k_d and mean effective fetch before and after island establishment are shown in Figure 3. Under 1992 conditions, daily TSS and k_d were very high during period of sediment resuspension, coinciding with large fetches during periods of high winds. Simulated daily TSS and kd declined in June and early September as a result of reduced fetch after island establishment.

POTAM simulations suggested that Sago Pondweed shoot biomass and tuber production were impacted as a result of frequent resuspension and low k_d (Figure 4). Low tuber dry mass after the first year of growth resulted in low shoot and tuber biomass production during the second year. Growth and persistence was unsustainable over the 5-year period. In contrast, simulated Sago growth and tuber production were persistent under conditions of island establishment. Maximum shoot biomass, tuber dry mass density and dry mass per tuber for September are shown in Figure 5. In general, model simulations suggested that island establishment and fetch reduction resulted in improvement in underwater light condition for successful Sago growth and persistence over a five year period.

References:

Bailey, M.C., & D.P. Hamilton, 1997. Wind induced sediment resuspension: A lakewide model. Ecological Modeling 99: 217-228.

Bengtsson, L., & T. Hellström, 1992. Wind induced resuspension in a small shallow lake. Hydrobiologia 241: 163-172.

Best, E. P. H., & W.A. Boyd. 2003a. POTAM (Version 1.0): A Simulation Model for Growth of Sago Pondweed. ERDC/EL SR-03-1, U. S. Army Engineer Research and Development Center, Vicksburg, MS.

Best, E. P. H., & W.A. Boyd. 2003b. A Simulation Model for Growth of the Submersed Aquatic Macrophyte Sago Pondweed (*Potamogeton pectinatus L.*). ERDC/EL TR-03-6, U. S. Army Engineer Research and Development Center, Vicksburg, MS.

Coastal Engineering Research Center, 1984. Shore protection manual, Volume 1. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi, USA.

Hamilton, D.P., & S.F. Mitchell, 1996. An empirical model for sediment resuspension in shallow lakes. Hydrobiologia 317**:** 209-220.

James, W.F., & J.W. Barko, 1994. Macrophyte influences on sediment resuspension and export in a shallow impoundment. Lake and Reservoir Management 10:95-102.

Luettich, R.A., D.R.F. Harleman, & L. Somyódy, 1990. Dynamic behavior of suspended sediment concentration in a shallow lake perturbed by episodic wind events. Limnology and Oceanography 35: 1050-1067.

Plumb, R.H., 1981. Procedures for handling and chemical analysis of sediment and water samples. Technical Report EPA/CE-81-1. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

Tsai, C.H., & W. Lick, 1986. A portable device for measuring sediment resuspension. Journal of Great Lakes Research 12:314-321.

Table 1. Values used as model parameters for estimating TSS in Marsh Lake.

Parameter	Value	
τ_c	2.3	dynes cm^{-2}
A	1275	
n	0.8	
ω_s	0.0005	cm s^{-1}
h	0.6	m
t	15	min
$C_{background}$	20	mg/L
$C_{initial}$	20	mg/L

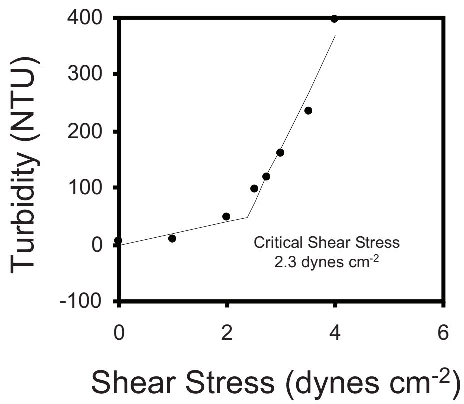

Figure 1. Variations in turbidity versus applied shear stress measured in the laboratory using a particle entrainment simulator.

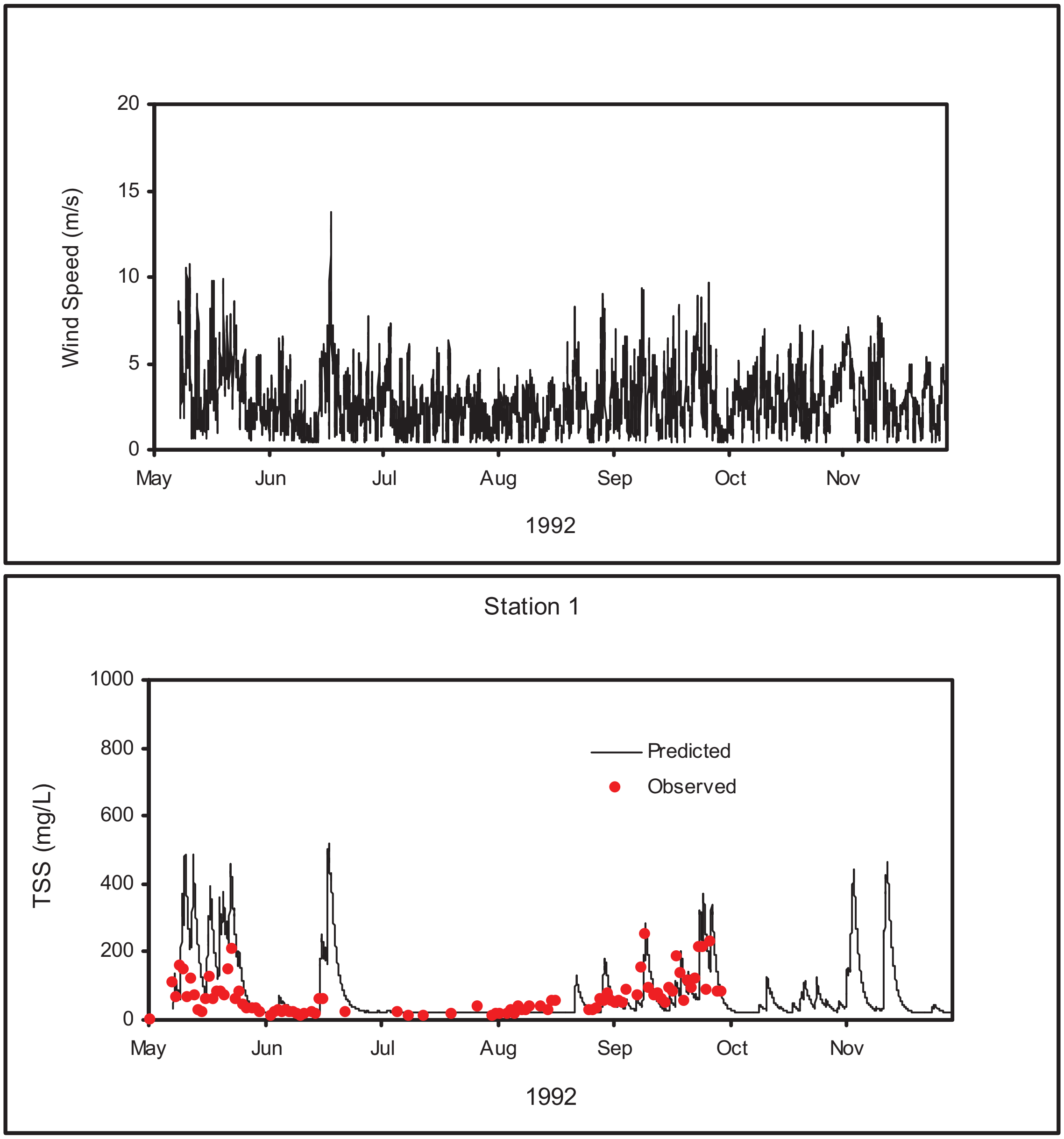

Figure 2. Seasonal Variations in wind speed (upper) and predicted versus observed total suspended sediment (TSS; lower).

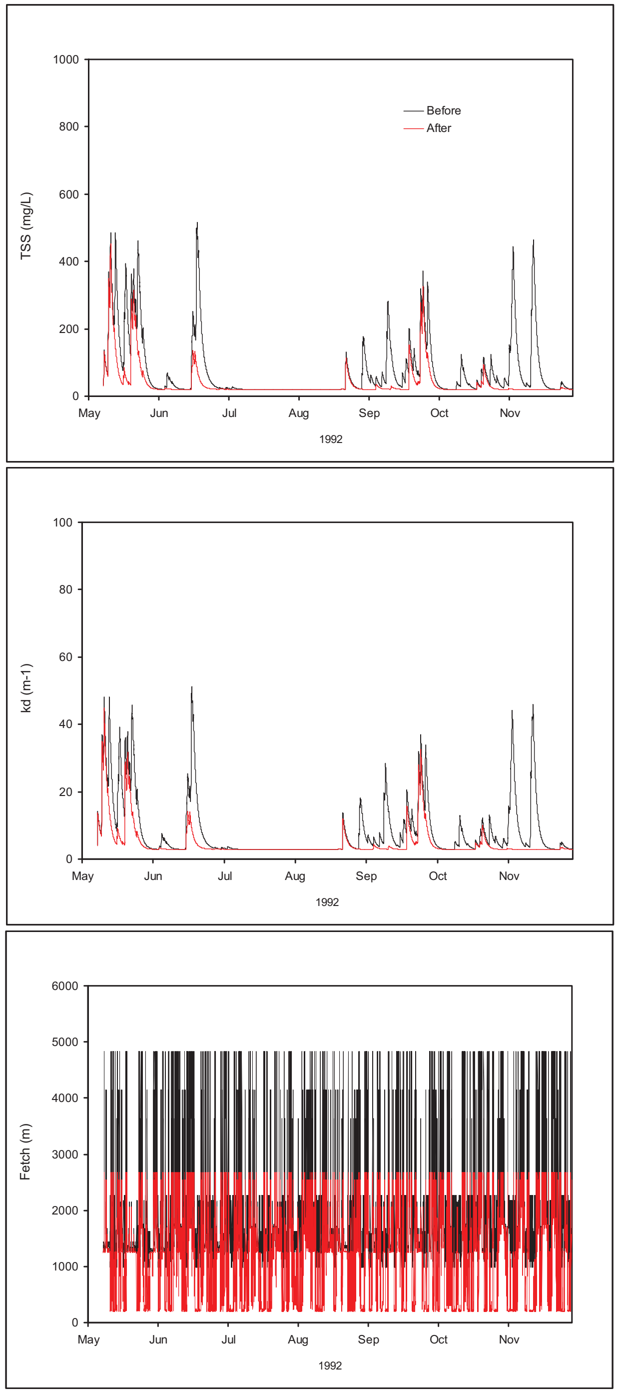

Figure 3. Seasonal variations in simulated total suspended sediment (upper), the light attenuation coefficient (middle), and effective fetch (lower) before and after island establishment in Marsh Lake.

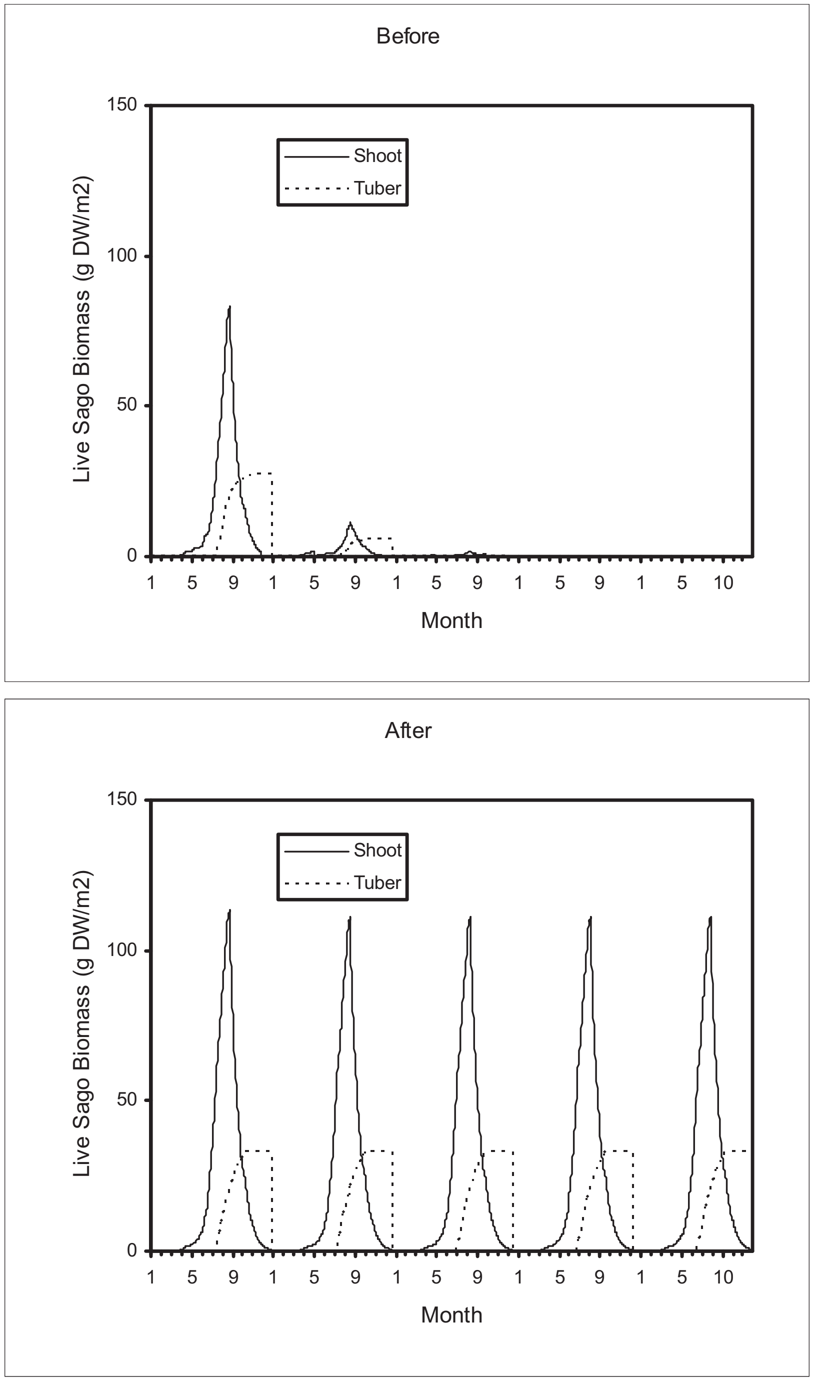

Figure 4. Variations in live sago shoot and tuber biomass over a 5 year period before (upper) and after (lower) island establishment in March Lake.

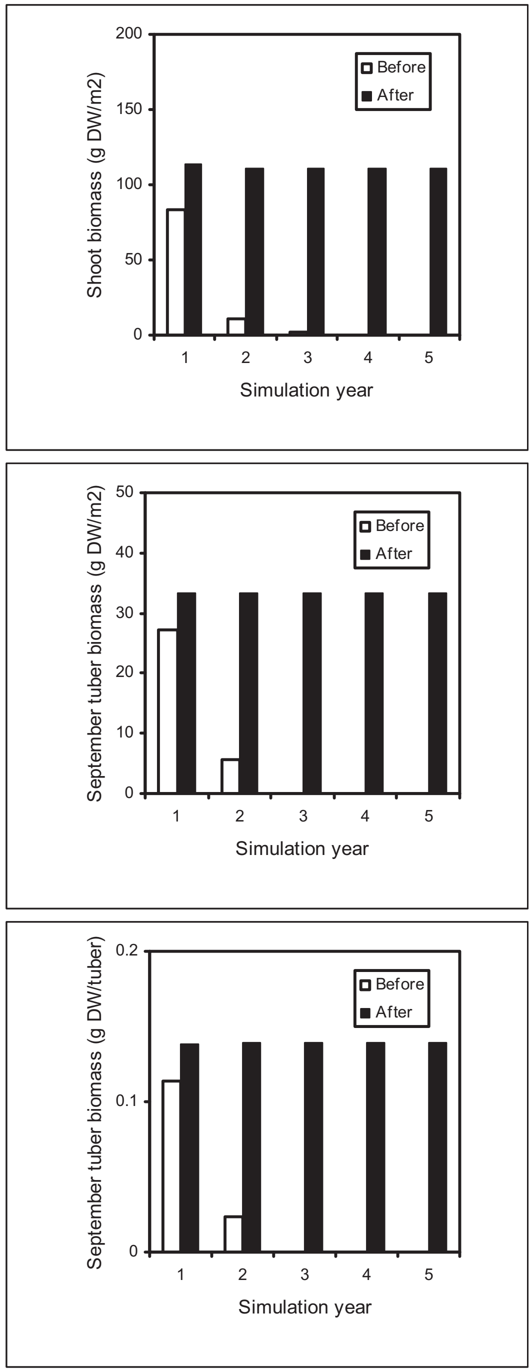

Figure 5. Variations in simulated maximum Sago shoot biomass (upper), tuber density (middle), and tuber biomass in September (lower) over a 5 year period before and after island establishment.